The Scalars $f_0(980)$ and $a_0(980)$ as Hadronic Molecules

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Abstract

We discuss the hadronic molecule issue in the light and heavy meson sector. Thereby we use the radiative decays of the scalars $f_0(980)$ and $a_0(980)$ to study its possible molecular $K\bar{K}$ structure. Further on we extend our formalism to mesons with open charm and strangeness, $D^*_{s0}(2317)$ and $D_{s1}(2460)$, whose hadronic molecule interpretation is analyzed in weak decays with $f_0(980)$ in the final state.

Key words: hadronic molecules, weak decays, electromagnetic decays, light, charm and bottom mesons
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1. Introduction

There is an ongoing discussion on the structure issue of mesons such as for instance the possible existence of hadronic molecules in the meson sector. In particular mesons lying slightly below a threshold are good candidates for meson-meson bound states. In the following we use a framework which allows for a consistent and fully gauge invariant analysis of hadronic bound states. In addition, the method considers finite size effects which arise due to the extended structure of hadronic molecules.

In the first part we concentrate on the radiative decays of the scalars $f_0(980)$ and $a_0(980)$ within a $K\bar{K}$ bound state assignment [1]. In the second part we extend our calculations by possible candidates for a molecular structure with open charm and strangeness which are the scalar $D^*_{s0}(2317)$ -a possible DK bound state- and the axial $D_{s1}(2460)$ lying close to D^*K threshold. Here we study the weak decays with a second hadronic molecule in the final state, the $f_0(980)$ [2].

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2. Theoretical framework

In the present approach mesons lying close to a threshold are assumed to be pure hadronic molecules. In particular we assign $S = K\bar{K}$ ($S = f_0, a_0$), $D^*_{s0} = DK$ and $D_{s1} = D^*K$, where K, D and D^* represent the isospin doublets (see [3]).

The basic element of our model is provided by the nonlocal Lagrangian describing the coupling of the hadronic molecule H to the respective constituent mesons M_1 and M_2

$$\mathcal{L}_{HM_1M_2} = g_H H(x) \int dy\, \Phi_H(y^2)\, M_1(x + w_{21}y)\, M_2(x + w_{12}y) + \text{H.c.} \tag{1}$$

with $w_{ij} = \frac{m_i}{m_i+m_j}$ and the coupling constant g_H.

Finite size effects are considered by the vertex function $\Phi(y^2) = \int \frac{d^4k}{(2\pi)^4} e^{-iky}\widetilde{\Phi}(-k^2)$. In momentum space we use a Gaussian form $\widetilde{\Phi}(k_E^2) = \exp(-k_E^2/\Lambda^2)$ with the size parameter $\Lambda = 0.7$ - 1.3 GeV. Provided that the decay amplitude is free of UV divergences we also compute the local limit, where $\Lambda \to \infty$ simulates point-like interaction.

A self-consistent description of bound states is given by the compositeness condition [4], where we realize a composite object by setting its renormalization constant Z_H to zero. $Z_{f_0} = 1 - g_H^2 \tilde{\Pi}'(m_H^2) = 0$ is characterized by the derivative of the mass operator $\Pi(m_H^2)$ allowing for a consistent determination of the coupling g_H.

3. Radiative decays

Electromagnetic interaction is included by minimal substitution. In case of nonlocal Lagrangians (1) we write $M^{\pm}_{1,2}(y) \to \exp\Big[\mp ie\int\limits_x^y dz_\mu A^\mu(z)\Big] M^{\pm}_{1,2}(y)$ [5] which results in additional diagrams contributing to the radiative decays (see e.g. Fig. 1 c)). In the hadronic molecule picture all decays proceed via intermediate constituents, here by kaon loops.

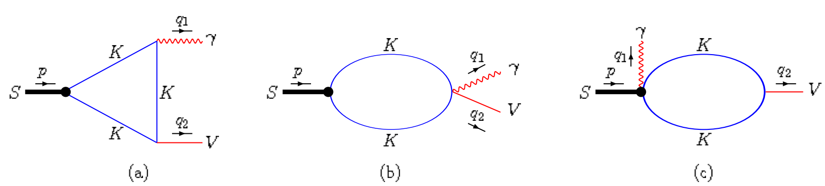

Fig. 1. Radiative decays of $S \to V\gamma$ with ($S = f_0(980), a_0(980)$, $V = \rho, \omega$).

The coupling of the kaons to the vectors $V = \rho, \omega$ is given by the standard Lagrangian $\mathcal{L}_{VK\bar{K}} = g_{\rho K\bar{K}} \boldsymbol{\rho}^\mu \bar{K} \boldsymbol{\tau}\, i\partial_\mu K + \sum\limits_{V=\phi,\omega} g_{VK\bar{K}} V^\mu \bar{K}\, i\partial_\mu K + h.c.$ with $g_{\rho K\bar{K}} = g_{\omega K\bar{K}} = \frac{g_{\phi K\bar{K}}}{\sqrt{2}} = 3$ fixed by $SU(3)$ symmetry relations. Our results for the two photon decays and the decays with a final vector meson are summarized in Tabs. 1 and 2. For the production of f_0 and a_0 in ϕ decays we obtain $\Gamma(\phi \to f_0\gamma) = 0.64$ keV and $\Gamma(\phi \to a_0\gamma) = 0.42$ keV.

4. Weak decays

Besides the light meson sector the present framework can also be applied to heavy mesonic bound states such as the D^*_{s0} and D_{s1}. The weak decays $D^*_{s0} \to f_0 X$ and

Table 1
Decay widths $\Gamma(S \to \gamma\gamma)$, $(S = f_0, a_0)$ in keV.

$\Gamma(f_0 \to \gamma\gamma)$		$\Gamma(a_0 \to \gamma\gamma)$	
Data [6]	$0.29^{+0.07}_{-0.09}$	Data [7]	0.3 ± 0.1
Our (Λ=1 GeV)	0.25	Theo. (Λ=1 GeV)	0.19
Our (local)	0.29	Theo. (local)	0.23

Table 2
Decay widths $\Gamma(S \to V\gamma)$ in keV.

Decay mode	nonlocal	local
$\Gamma(f_0 \to \rho\gamma)$	7.58	8.09
$\Gamma(f_0 \to \omega\gamma)$	7.12	7.57
$\Gamma(a_0 \to \rho\gamma)$	6.59	7.18
$\Gamma(a_0 \to \omega\gamma)$	6.22	6.76

$D_{s1} \to f_0 X$ proceed via the intermediate constituents of the respective final and initial hadronic molecules (see Fig. 2). The couplings are either taken from experiment or, in the case of hadronic molecules, fixed by the compositeness condition. The results for

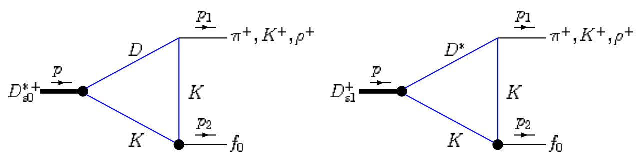

Fig. 2. D^*_{s0} and D_{s1} weak decay processes.

the respective D^*_{s0} decay modes differ by an order of magnitude as indicated in Tab. 3. Together with $\Gamma(D_{s1} \to f_0\pi) = (2.85$ - $4.35)\cdot 10^{-11}$ GeV (Λ_D= 1 - 2 GeV) the weak decays span a region of four orders of magnitude.

Table 3
Decay widths of the weak decays $D^*_{s0} \to f_0 X$ $(X = K, \pi, \rho)$ in GeV.

	nonlocal	local
$\Gamma(D^*_{s0} \to f_0 K)$	(1.42 - 1.53)$\cdot 10^{-15}$	$2.75 \cdot 10^{-15}$
$\Gamma(D^*_{s0} \to f_0 \pi)$	(1.14 - 1.26)$\cdot 10^{-14}$	$2.35 \cdot 10^{-14}$
$\Gamma(D^*_{s0} \to f_0 \rho)$	(1.08 - 1.11)$\cdot 10^{-13}$	$1.60 \cdot 10^{-13}$

5. Conclusions

The present QFT approach for hadronic molecules based on the Weinberg condition obeys Lorentz covariance and gauge invariance. It provides a consistent determination of production and decay properties. The model includes finite size effects controlled by the size parameters Λ. The electromagnetic decay and production properties are in good agreement with data. Further on we extended our formalism to weak transitions between hadronic molecules which could possibly test the molecular structure as well.

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